successful in reducing flooding in urban areas. They are also important areas for farming. The realization of their relatively low-cost benefits to flood control is leading to the consideration of additional bypasses, especially in the San Joaquin Valley. There is also a growing realization that bypasses can be important habitat for waterfowl, for fish spawning and rearing, and possibly as a sources of food and nutrients for estuarine foodwebs. For example, when the Yolo Bypass is flooded, it effectively doubles the wetted surface area of the Delta, mostly in shallow-water habitat. Managing the bypasses for the benefit of fish and wildlife, however, may conflict with their use for flood control and farming. Therefore, there is a major need to evaluate existing bypasses as habitat to reduce management conflicts. New or expanded bypasses and managed flood basins should also be designed with the needs of fish and wildlife in mind (Strategic Plan 2000).

OPPORTUNITIES: Undertake floodplain restoration on a broad scale, where land or easements can be acquired and where the river hydrology includes (or can be made to include) sufficiently high flows to inundate floodplain surfaces. Restoration of floodplain function can produce many benefits, such as reducing stress on remaining levees, reducing excessive channel scour, and encouraging establishment of riparian vegetation over a larger area within the adjacent floodplain. A range of possible measures will need to be employed to fit local conditions, such as widening flood bypasses or creating new ones; setting levees back, creating backup levee systems, or deauthorizing specific levee reaches; constructing armored notch weirs in levees and purchasing flood easements to restore flood basin storage functions; or implementing measures described in item two above to increase the frequency and duration of overbank flow onto existing floodplains. Reactivating the historical floodplain can provide effective reliable, and cost effective flood storage while restoring important ecological processes (Strategic Plan 2000).

VISION

The vision for natural floodplains and flood processes is to conserve existing intact floodplains and modifying or removing barriers to overbank flooding to reestablish aquatic, wetland, and riparian floodplain habitats.

Measures for conserving and enhancing natural floodplains and flood processes are complimented by the visions for natural sediment supply, natural fluvial geomorphology, and stream meander corridors. If the floodplain, meander width, sediment supply, and natural or simulated flood peaks are in place, the river will respond by creating natural landforms. These natural landforms will support self-sustaining vegetation communities and aquatic and terrestrial habitats. Even partial restoration or simulation of natural physical processes and floodplains will enhance channel characteristics and resultant habitats.

Conservation and management of natural existing floodplains should be promoted. Cooperative efforts with the U.S. Army Corps of Engineers and California Department of Water Resources (DWR) should be developed to map and describe the hydrologic characteristics and conditions of all remaining natural riverine and estuarine floodplains not separated from channels by levees or irreversible stream incision. Remaining floodplains that interact with bankfull discharge and higher high tides should be maintained as active floodplains because of their ecological functions and habitat potential, as well as their flood management benefits.

Flood processes and floodplain functions can be restored to many rivers, streams, and estuaries where levees are no longer essential for flood safety or where agricultural uses are marginal or problematic because of poor drainage, high maintenance costs, or frequent sand deposition.

INTEGRATION WITH OTHER RESTORATION PROGRAMS

Attaining the vision for natural floodplains and flood processes will involve coordination with other programs and organizations, including:

- Upper Sacramento River Fisheries and Riparian Habitat Advisory Council (SB1086 group) efforts and river corridor management plans implemented for the Sacramento River;
- studies underway by the state Reclamation Board and DWR to evaluate the aftermath of the January 1997 flood damage, levee stability, and future floodplain risk assessment;

- the U.S. Army Corps of Engineers and the Reclamation Board's Sacramento and San Joaquin River Basins Comprehensive Study, including more comprehensive floodplain management and river ecosystem restoration opportunities;
- proposed riparian habitat restoration and floodplain management studies for the San Joaquin River and its major tributaries, under supervision of the State Reclamation Board and Corps of Engineers, including potential new flood bypass systems and expanded river floodplains on lands recently acquired by the California Department of Parks and Recreation and U.S. Fish and Wildlife Service (USFWS);
- the San Joaquin River Parkway Plan;
- various plans for the restoration of tidelands (i.e., tidal floodplains) in the north San Pablo Bay and Suisun Bay; and
- multiagency plans or studies to breach levees and reopen floodplains of islands of the north Delta, including Liberty and Prospect Islands, and Little Holland Tract.

LINKAGE TO MULTI-SPECIES CONSERVATION STRATEGY

Stream meander is a dynamic ecological process that typifies a healthy river corridor or riverine ecosystem. A river-based ecosystem in the Central Valley extends laterally over its entire floodplain and longitudinally from its headwaters to the Delta or Bay. It may even extend beyond to hydrologically connected aquifers (California State Land Commission 1993). This view of floodplains as essential components of a living river system is critical to the protection and restoration of aquatic, riparian, and terrestrial species addressed by the Multi-Species Conservation Strategy (2000).

LINKAGE WITH OTHER ECOSYSTEM ELEMENTS

Maintenance of natural floodplain and flood processes in the rivers and Delta is closely linked with stream flow, sediment supply, and stream meander processes, riparian, wetland, and aquatic habitats, and many stressors including dams, levees, bank protection, dredging, and gravel and sand mining in the floodplain.

OBJECTIVES, TARGETS, ACTIONS, AND MEASURES

The Strategic Objective for natural floodplains and flood processes is to reestablish floodplain inundation and channel-floodplain connectivity of sufficient frequency, timing, duration, and magnitude to support the restoration and maintenance of functional natural floodplain, riparian and, riverine habitats.

LONG-TERM OBJECTIVE: Reestablish active inundation of floodplains with area targets and inundation frequencies (1-5 years) to be set for each major alluvial river (where feasible) based on probable pre-1850 floodplain inundation regimes and on existing opportunities to modify existing land uses.

SHORT-TERM OBJECTIVE: Reestablish active inundation of at least half of all remaining unurbanized floodplains in the Central Valley, where feasible.

RATIONALE: Frequent (often annual) floodplain inundation was an important attribute of the original aquatic systems in the Central Valley and was important for maintaining diverse riverine and riparian habitats. Important interactions between channel and floodplain include overflow onto the floodplain, which (1) reduces the cutting down of the channel, (2) acts as a "pressure relief valve", permitting a larger range of sediment grain sizes to remain on the channel bed, (3) increases the complexity and diversity of instream and riparian habitats, and (4) stores floodwater (thereby decreasing flooding downstream). The floodplain also provides shading, food organisms, and large woody debris to the channel. Floodplain forests serve as filters to improve the quality of water reaching the stream channel by both surface flow and groundwater. The actions necessary to reestablish active inundation will probably require major land purchases or easements, and financial incentives to move existing floodplain uses elsewhere, as has been done in the Midwest since 1993. Obviously, artificial inundation events will have to be planned to take into account other needs for stored water, including increased summer flows.

STAGE 1 EXPECTATIONS: All existing unurbanized floodplains in the Central Valley will have been identified and a priority list for floodplain restoration projects developed. Strategies for the restoration of natural channel and floodplain dynamics will have been developed and implemented in at least two large demonstration projects. Results of initial floodplain reactivation projects will be used to increase understanding of channel-floodplain interactions and the potential for restoration of processes.

RESTORATION ACTIONS

General targets to restore health to floodplains and flood processes include:

- conserving and expanding floodplains of Central Valley rivers and Bay-Delta by augmenting the natural flood processes including increasing the average floodplain width and linear extent of low areas beyond channel banks subject to bankfull discharge;
- promoting flood detention in flood basins and, where appropriate, encouraging wetland formation;
- increasing the frequency of inundation of vegetated floodplains connected to rivers and tidal channels; increasing the extent of tidal inundation at or above mean high tide; and
- reducing the extent of trapezoidal channels within levees and floodways; and increasing the acreage and connectivity of natural habitat areas within active floodplains of rivers and estuaries.

Floodplain expansion can be implemented in one of the following ways:

- Set back levees along channels and tidal sloughs to expand the width of the river's floodplain within the levee system. This approach should be evaluated on many rivers and tributaries as part of the overall reevaluation of the valley's flood control infrastructure and floodplain management policies.
- Acquire flood easements on agricultural and natural lands to allow a greater frequency and extent of floodplain inundation.
- Breach or remove levees from channels that are confined by narrow levee corridors, where feasible. In farmed areas, much of the land could continue to be farmed, if desirable, because most flooding would occur in limited areas and only during the non-growing season. This approach may have wide applicability to the low-lying plains of the San Joaquin River and lower tributaries and should be studied together with levee upgrades.
- Modify bypass and channel vegetation management policies to allow greater vegetative cover on existing floodplains. Where needed, compensate for increased channel roughness by implementing other flood control projects upstream that reduce peak flood water surface elevations.
- Expand floodplains and bypasses and add additional flood relief structures to reduce maximum flood stage in the channels. Expanded floodplains will allow for more vegetation and habitat within the channels, as well as the potential to provide greater flood protection. The Corps of Engineers and the Governor's Flood Control Task Force will be evaluating the need for new flood relief structures for the Sacramento and Feather Rivers along the Colusa Basin and Sutter Basin and for the San Joaquin River and lower tributaries along the extensive historic river plains.
- Breach or remove levees along Delta sloughs and former diked tidelands of the Bay.

MSCS CONSERVATION MEASURES

The following conservation measures were included in the Multi-Species Conservation Strategy (2000) to provide additional detail to ERP actions that would help achieve species habitat or population goals. Although the measures were developed specifically for evaluated species, some measures have direct relationships to the extent to which floodplains and flood processes influence habitat quality and quantity or have beneficial effects on evaluated species.

- Coordinate protection, enhancement, and restoration of floodplains with other federal, state, and regional programs (e.g., the SB 1086 program, the Corp's Sacramento and San Joaquin Basin Comprehensive Study, the Anadromous Fish Restoration Program, and U.S. Fish and Wildlife Service recovery plans) that could affect management of current and historic habitat use areas to avoid potential conflicts among management objectives and identify opportunities for achieving multiple management objectives.
- Initial species recovery efforts should be directed to locations where there are immediate opportunities for protection, enhancement, or restoration of suitable habitat.
- To the extent consistent with Program objectives, direct ERP actions towards setting back levees in the south Delta to increase shallow water habitat.
- To the extent consistent with Program objectives, mobilize organic carbon in the Yolo Bypass to improve food supplies by ensuring flow through the bypass at least every other year.
- Identify and implement measures to eliminate stranding of green sturgeon in the Yolo Bypass or to return stranded fish to the Sacramento River.
- Implement management measures identified in the proposed recovery plan for the Sacramento River winter-run chinook salmon (National Marine Fisheries Service 1997).
- Implement applicable management measures identified in the restoration plan for the Anadromous Fish Restoration Program (U.S. Fish and Wildlife Service 1997) and the recovery plan for native fishes of the Sacramento-San Joaquin Delta (U.S. Fish and Wildlife Service 1996).
- Consistent with Program objectives, improve the frequency, duration, and extent of bypass flooding in all years.
- Develop a water management plan to allocated multiyear water supply in reservoirs to protect drought year supplies and source of winter-spring Delta inflow and outflow needed to sustain splittail and their habitats.
- Direct ERP actions proposed for the Stanislaus River towards protecting, enhancing, and restoring suitable riparian and associated flood refuge habitats in and adjacent to occupied habitat at Caswell Memorial State Park.
- Restore and protect suitable open floodplain habitat for Delta coyote-thistle along the San Joaquin River.
- To the extent consistent with CALFED objectives, manage lands purchased or acquired under conservation easements to maintain or increase current population levels of resident evaluated species.

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◆ Bay-Delta Hydrodynamics

INTRODUCTION

The Delta of today is greatly altered from its historical condition. Historically, a complex, dendritic array of channels drained extensive marsh plains. Now, theses channels have been replaced by a greatly simplified network of uniform channels.

The Delta waterways generally contain fresh water, with brief incursions of slightly brackish water into the northern and western Delta. This incursion is more pronounced during the spring and early summers of very dry years when the discharges from the Sacramento and San Joaquin rivers are low. This differs from the natural pattern in which brackish water intrusion naturally occurred in late summer and early fall.

Beginning in the mid 1800s, the Delta has been subject to the effects of alteration of the natural seasonal patterns of river discharge, Delta morphology, and tidal prism. These factors interact to determine water movement patterns and salinity distribution in the Delta. Salinity levels in Delta waters is primarily a result of tidal prism and stage, and net Delta outflow. It is also influenced by prevailing wind direction and velocity. Daily tidal cycles result in flows in the lower San Joaquin River of up to 300,000 to 400,000 cfs, and the spring-neap cycle alters water surface elevations and salinity levels on a monthly basis.

Other factors that now contribute to alteration or moderation of historic flow patterns in Delta waterways and channels include operation of the CVP/SWP pumping plants in the south Delta, the Suisun Marsh Salinity Control Structure, the Delta Cross Channel (DCC), and a temporary flow barrier on the San Joaquin River at the head of Old River. The DCC and Old River Barrier affect flow rates, direction, and water surface elevations. At times, these factors contribute to the creation of unnatural flow patterns which is particularly evident in the channels of the southern and central Delta.

Hydrodynamic processes are an extremely important aspect of the Bay-Delta system and refers to the seasonal and daily direction and velocity of flows in Bay-Delta channels. The direction and velocity of flow and their distribution in time and location are important factors in habitat preferences of Bay-Delta organisms, erosion and sedimentation processes, migratory cues for organisms, and many other ecological processes and functions in the Bay-Delta. Major factors that affect hydrodynamics of Bay-Delta channels include streamflow, sediment composition, and channel configuration.

Flow conditions in Delta channels affect foodweb production, transport of organisms through the Delta, and vulnerability to south Delta pumping plant diversions. The Bay-Delta estuary provides important fish spawning, rearing, and migrating habitats. The Bay-Delta also serves as an important link in nutrient cycling and provides for high levels of primary (plant) productivity that supplies the aquatic foodweb.

RESOURCE DESCRIPTION

Nonimpeded tidal action into tidal wetlands affects sediment and nutrient supplies into those wetlands and complements natural marsh successional processes. Tidal action associated with flows out of tidal wetlands transports nutrients and organic carbon into aquatic habitats of the Bay-Delta.

Hydrodynamic patterns in the Delta are important to the survival of delta smelt, longfin smelt, striped bass, chinook salmon, and other fish dependent on the Sacramento-San Joaquin Delta. Unfavorable hydrodynamic conditions, such as net flow moving south to Delta export facilities instead of moving west toward Suisun Bay, reduce fish survival.

Improved hydrodynamic patterns will increase residence times of Delta water; provide more natural downstream flows; and improve rearing and spawning habitat, nutrient cycling, and foodweb integrity.

Delta hydrodynamics are determined by a combination of flow parameters including Delta inflow, Delta diversions, tidal flows, and facility operations (e.g., operation of the DCC gates). Cross-Delta water flow to the south Delta pumping plants reduces residence time of water in the Delta and alters flow direction and magnitude.

Unfavorable hydrodynamic conditions decrease juvenile chinook salmon survival as they migrate from the Sacramento River through the Delta. With a high rate of north-to-south flow from the Sacramento River through the DCC and Georgiana Slough into the central Delta, young salmon may become lost or delayed within the Delta, or may become more susceptible to being drawn to the south Delta pumping plants.

Favorable hydrodynamic conditions are important for chinook salmon because the Delta is a migration corridor and also provides rearing habitat. Juvenile chinook salmon rearing in the Delta are exposed to adverse hydrodynamic conditions for approximately 1-3 months until they are ready to migrate to the ocean.

Other species, including striped bass and delta smelt, are also subject to being drawn south across the Delta to the pumping plants. Because the water has a short residence time, the food supply is generally poor for those fish drawn into or residing in the central and southern Delta.

VISION

The vision for hydrodynamic processes in the Sacramento-San Joaquin Delta is to restore channel hydrodynamics to conditions more like those that occurred during the mid-1960s to provide migratory cues for aquatic species; transport flows for eggs, larvae, and juvenile fish; and transport of sediments and nutrients.

INTEGRATION WITH OTHER RESTORATION PROGRAMS

The objective of one current program, the Temporary Barriers Program in the south Delta, is to improve the quantity and quality of irrigation water to agricultural users in the south Delta. A secondary objective is to provide a physical barrier in spring at the head of Old River at its junction with the San Joaquin River to reroute outmigrating San Joaquin fall-run chinook salmon downstream and away from the export facilities. In fall, a partial rock barrier modifies channel hydrodynamics to reduce the risk of dissolved oxygen blocks near Stockton and to ensure that a greater percentage of attraction water from natal streams reaches the Central and West Delta Ecological Unit.

The DCC gates are required to be closed under the terms of the National Marine Fisheries Service's biological opinion on winter-run chinook salmon and the 1995 Water Quality Control Plan to reduce impacts on salmon migrating down the Sacramento River. The gates can be closed at the request of the California Department of Fish and Game for half of November, December, and January. The DCC gates are then closed from February 1 through May 15.

LINKAGE TO MULTI-SPECIES CONSERVATION STRATEGY

Hydraulic and hydrodynamic patterns in the Delta and lower bays are critical elements in the transport of nutrients, foodweb organisms, fish eggs, larval and older fishes. These flow and flood-ebb, and circulation patterns are critical to achieving the recovery of tidal perennial aquatic and saline emergent wetland dependent species evaluated in the Multi-Species Conservation Strategy (2000).

LINKAGE WITH OTHER ECOSYSTEM ELEMENTS

Bay-Delta hydrodynamics are closely linked to the health of aquatic habitats in the Bay-Delta and the aquatic resources that depend on these health habitats. These include:

- tidal perennial aquatic habitat,
- Delta sloughs, and
- midchannel islands and shoals.

Species and species groups that are dependent on healthy hydrodynamic conditions in the Bay-Delta include:

- delta smelt,
- longfin smelt,
- striped bass,
- chinook salmon, and
- many other estuarine and resident aquatic species.

OBJECTIVE, TARGETS, ACTIONS, AND MEASURES

The Strategic Objective for Bay-Delta hydrodynamics is to establish and maintain hydrologic and hydrodynamic regimes for the Bay and Delta that support the recovery and restoration of native species and biotic communities, support the restoration and maintenance of functional natural habitats, and maintain harvested species.

LONG-TERM OBJECTIVE: Have a hydrodynamic regime in the Delta, Suisun Bay, San Pablo Bay, and San Francisco Bay that is favorable to maintenance of large, self-sustaining populations of species and habitats treated separately under goals 1, 3 and 4.

SHORT-TERM OBJECTIVE: Develop a more favorable hydrodynamic regime during key spawning and rearing times for native species and desirable non-native species. Select and implement water project operations measures to the extent feasible to support this hydrodynamic regime. Evaluate other measures and actions designed to create favorable conditions for depleted species and implement them where feasible.

RATIONALE: The restoration to abundance of most, if not all, of the native species and habitats in the Sacramento-San Joaquin estuary depends on the restoration and maintenance of a Bay-Delta hydrodynamic regime that supports important ecological functions such as sustaining a productive food web, providing spawning, rearing, and feeding habitat for estuarine and anadromous fish, and supporting migration of adult and juvenile fish. Human activities such as reduced Delta inflow, exports from the Delta and conversion of tidal wetlands have had a large influence on the natural hydrodynamic regime of the Bay-Delta. There are opportunities to restore or simulate, where and when appropriate, a more natural hydrodynamic regime, particularly in the February through June period, that sustains ecological functions and meets the life requirements of the fish and wildlife in or dependent on the Bay-Delta. As more is learned about the hydrodynamics of the estuary, direct and indirect modifications of estuarine processes (in an adaptive management context) should continue.

STAGE 1 EXPECTATIONS: Implementation of actions to restore or simulate a more natural hydrodynamic regime in the February through June period will be underway. Actions will include modifications to Delta inflow patterns and export operations during that period as well as restoration of tidal action to areas within the Bay-Delta. Studies on the factors affecting the abundance of key organisms should be ongoing, And a basic understanding of how effective the water operations measures have been for the at-risk species with continued exports from the south Delta should be developed and used to assess the need for a dual conveyance facility and to implement other strategies for their recovery.

RESTORATION ACTIONS

The general target for restoring and maintaining healthy Bay-Delta hydrodynamics is to focus on restoring hydrodynamic patterns typical of those exhibited when the ecosystem was functioning in a healthy state (e.g., 1960s).

The general approach to attain the target include the following:

- The effects of water exports and lower riverflows can be reduced by altering Delta channel configurations to improve system hydrodynamics. The two ecological units that have the greatest need for improved hydrodynamics are the South Delta and Central and West Delta Ecological Units.
- Modify Delta inflow patterns and export operations during the February through June period to more closely mimic hydrodynamic conditions that would have occurred under conditions in the mid-1960s.
- The greatest opportunities to restore hydrodynamic processes to reference levels that occurred when the estuary was healthier are linked to the water and storage alternatives. The potential for restoration is limited by a water storage and transport component that has its only export facilities located in the South Delta Ecological Unit. Under that condition, increased storage upstream or downstream of the Delta

could reduce exports in portions of some months and improve hydrodynamics during those times. Other more limited opportunities exist that are associated with storing water in the Delta, using physical barriers in strategic locations in the Delta, broadening specific sloughs to increase their flow-bearing capacity while reducing water velocities, and restoring large acreages of tidal wetlands and tidal channels to increase the tidal volume of the estuary.

MSCS CONSERVATION MEASURES

The following conservation measures were included in the Multi-Species Conservation Strategy (2000) to provide additional detail to ERP actions that would help achieve species habitat or population goals. Although the measures were developed specifically for evaluated species, some measures have a direct relationship to improving Bay-Delta hydrodynamic conditions to support the recovery and maintenance of at-risk species.

- Coordinate protection, enhancement, and restoration of occupied delta smelt habitats with other federal state, and regional programs (e.g., the San Francisco Bay Area Wetland Ecosystem Goals Project, the SB 1086 program, the Corp's Sacramento and San Joaquin Basin Comprehensive Study, the Anadromous Fish Restoration Program, and U.S. Fish and Wildlife Service recovery plans) that could affect management of current and historic habitat use areas to avoid potential conflicts among management objectives and identify opportunities for achieving multiple management objectives.
- Allow delta smelt unrestricted access to suitable spawning habitat and protect these areas from physical disturbance (e.g., heavy equipment operation) and flow disruption in the period from December to July by maintaining adequate flow and suitable water quality to attract migrating adults in the Sacramento and San Joaquin River channels and their tributaries, including Cache and Montezuma sloughs and their tributaries.
- Protect critical delta smelt rearing habitat from high salinity (>2 ppt) and high concentration of pollutants from the beginning of February to the end of August.
- To the extent consistent with CALFED objectives, protect the Sacramento and San Joaquin river and tributary channels from physical disturbance (e.g., sand and gravel mining, diking, dredging, and levee or bank protection and maintenance) and flow disruption (e.g., water diversion that result in entrainment and in-channel barriers or tidal gates) from the period February 1 to August 31.
- Improve January and February flows for the longfin smelt during the second and subsequent years of drought periods.
- Provide sufficient Delta outflows for the longfin smelt during December through March.
- Provide inflows to the Delta from the Sacramento River greater then 25,000 cfs during the March to May green sturgeon spawning period in at let 2 of every 5 years.
- Implement management measures identified in the proposed recovery plan for the Sacramento River winter-run chinook salmon (National Marine Fisheries Service 1997).
- Implement applicable management measures identified in the restoration plan for the Anadromous Fish Restoration Program (U.S. Fish and Wildlife Service 1997) and the recovery plan for native fishes of the Sacramento-San Joaquin Delta (U.S. Fish and Wildlife Service 1996).
- Modify operation of the Delta Cross Channel to minimize potential to increase exposure of splittail population in the Delta to the south Delta pumping plants.
- Modify operation of the barrier at the Head of Old River to minimize the potential for drawing splittail toward the sough Delta pumping plants.
- Consistent with CALFED objectives, design modifications to South Delta channels to improve circulation and transport of north of Delta water to the south Delta pumping plants to ensure habitat supports splittail and to not increase transport of splittail to the south Delta pumping plants.

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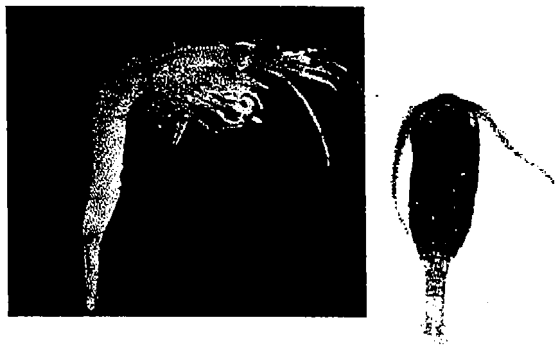
◆ BAY-DELTA AQUATIC FOODWEB



INTRODUCTION

The aquatic foodweb of the Bay-Delta ecosystem is the web of organisms through which energy transfers up through the different trophic levels from the lower level that includes the plants to the highest level that includes the fish, water birds, and marine mammals. Each level in the web receives energy from the lower levels. The lower or primary producer level gets energy from photosynthesis or basic forms of dissolved organic compounds in the water. The second level is generally the primary consumers or herbivores (e.g., bacteria and algae-eating zooplankton) that feed on the plants or plant products. Secondary and tertiary consumers are further up the foodweb.

Total productivity of the Bay-Delta estuary is dependent primarily on the amount of plant biomass produced and the efficiency in which the energy is transferred up through the higher levels of the web. The Bay-Delta aquatic foodweb is derived from energy created by many kinds of plants, some of which are grown in the Bay-Delta waters and adjacent riparian and wetland habitat, while others are from upstream or land production.

RESOURCE DESCRIPTION

Plant contributions to the estuary foodweb consist mostly of benthic algae and phytoplankton produced in the estuary and its watershed. "Benthic" foodweb organisms are bottom dwelling, whereas plankton spend most of their time drifting in the water column. Vascular-plant debris contributed from terrestrial or wetland communities adjacent to the system also contribute to the foodweb. Algae are generally small (diameter <0.1 millimeters [mm]), easily transported, and highly nutritious; whereas most vascular-plant debris begins as coarse particulate organic matter that must be colonized and partially decomposed by bacteria before being usable by invertebrates and fish.

The Bay-Delta foodweb has undergone many changes since the 1960s. Most notably, algal abundance (as measured by chlorophyll concentrations in waters of the estuary) has declined in important fish nursery areas of Suisun Bay and the western Delta. Lowered algal abundance in Suisun Bay coincides with very low Delta outflow during drier years, particularly in the drought years, such as 1977 and 1987-1992, and with very wet years, such as 1983 and 1995. However, many species of zooplankton underwent their largest declines between 1970 and 1980, well in advance of the 1987-1992 drought (Obreski et al. 1992). Chlorophyll levels greater than 20 micrograms-per-liter ($\mu g/l$) were present in Suisun Bay only twice since 1986.

Over the past three decades, chlorophyll concentrations upstream in the western Delta have been similar to those in Suisun Bay. As in Suisun Bay, concentrations are lower in dry years and very wet years. Such levels have been achieved in only two years since 1986.

A pattern of very low chlorophyll levels in Suisun Bay and the western Delta beginning in 1987 has caused concern among many scientists. These low levels may be the result of high densities of Asian clams (*Potamocorbula amurensis*) which colonized the Bay after being accidentally introduced from the ballast waters of ships. Large numbers of the clams colonized this area of the estuary during the drought period from 1987 to 1992.

Some of the plant production appearing in the Delta and Suisun Bay is washed down from south Delta channels and the San Joaquin River. Chlorophyll levels in these channels reached an average of more than 100 $\mu g/l$ in spring and summer of some years in the early 1970s. In the past two decades, productivity